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ADDENDUM TO PROCEEDINGS OF THE 10 MAY 1989 ANTIPROTON TECHNOLOGY WORKSHOP

A compilation of presentation materials from the workshop held at Brookhaven National Laboratory, jointly sponsored in accordance with the AL/DoE Memorandum of Agreement for Applied Research In Energy Storage support from Brookhaven National Laboratory

August 1989

Editor: Gerald D. Nordley

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Prepared for the **Astronautics Laboratory (AFSC)**

Air Force Space Technology Center
Space Systems Division
Air Force Systems Command
Edwards Air Force Base, California 93523-5000

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FOREWORD

This special report comprises the presentations provided by speakers at the Antiproton Technology Workshop held at Brookhaven National Laboratory (BNL) 10 may 1989 jointly sponsored under the Astronautics Laboratory (AFSC) / Department of Energy-BNL Memorandum of Agreement for support of Applied Research In Energy Storage (ARIES). This special report has been reviewed and approved in accordance with the distribution statement on the cover an on the DD form 1473.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This workshop, held at Brookhaven National Laboratory, 10 May 1989, was a follow-on to the Antiproton Science and Technology Workshops held at the RAND Corporation in Santa Monica through October 1987 following the Air Force Project Forecast II initiative in Antiproton Technology. The workshop was attended by about 50 researchers from a wide variety of disciplines, including medicine, particle physics, and the aerospace industry. New, more efficient technology for a variety of scientific, medical, and industrial uses could result from antiproton experiments proposed by workshop participants. Antiprotons are particles of antimatter which release highly penetrating radiation when they are stopped in normal matter. According to presentations at the Antiproton Technology Workshop this radiation can be used, in very small quantities, to image objects and determine their composition and density. In larger amounts, the radiation could be used to kill cancer tumors or produce highly localized heating and shock waves. DOE plans are contingent on potential user support.

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* Copies of viewgraphs were unavailable at the time of compilation (17 May 1989). They may be inserted if recieved later.

** Copies of presentation only in adendum.

Table 2. Attendees at the Antiproton Technology Workshop

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Smith, Gerald	Penn State U	Dep Phys	303 Osmond Lab.	University Park PA 16802	814 863 3076
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Toothacker, W. S.	Penn State		303 Osmond Lab	University Park PA 16802	814 863 3297
Von Herzen, Dr Brian	AntiM Corp		2379 Kalanianaole St	Hilo HI 96720	808 969 7061

STOPPING POWER OF MeV PROTON AND ANTIPROTON BEAMS

R. A. LEWIS

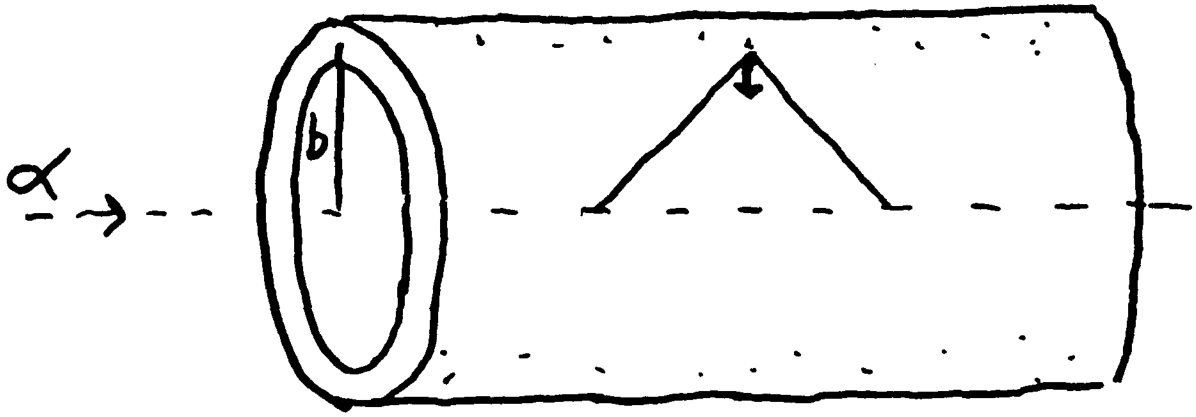
LABORATORY FOR ELEMENTARY PARTICLE SCIENCE
THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PA

PRESENTED AT THE ANTIPROTON TECHNOLOGY WORKSHOP
HELD AT BROOKHAVEN NATIONAL LABORATORY
10 MAY 1989

Stopping Power of MeV Proton and Antiproton Beams

R.A. Lewis, R. Kaualeiter, G.A. Smith,
W.S. Toothacker, M.G. Willis
Penn State University

Antiproton Technology Workshop
May 10, 1989
BNL



$$\Delta p_e \simeq F \Delta t$$

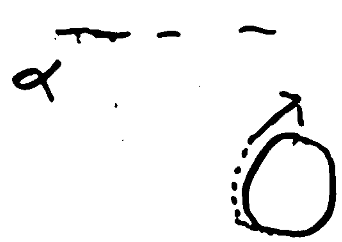
$$\Delta E_e = \frac{2 Z_\alpha^2 e^4}{m_e v^2} \cdot \frac{1}{b^2}$$

$$\frac{dE}{dx} = 4\pi n_e \cdot \frac{Z_\alpha^2 e^4}{m_e v^2} \int \frac{db}{b}$$

Impact Parameters

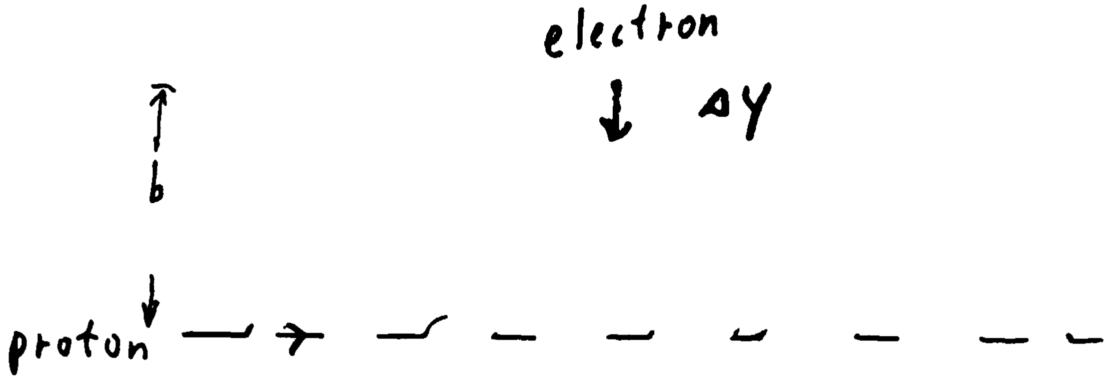
2 MeV α

$\Delta E = 43\,eV$	$0.27\,\mathring{A}$	
$\omega = v/b$	$1.5\,\mathring{A}$	b_{max}
distance of closest approach	$0.05\,\mathring{A}$	
de Broglie $\lambdabar$	$0.12\,\mathring{A}$	b_{min}



$$W = \int \vec{F} \cdot \vec{v}\, dt$$

Barkas Effect



$$\frac{\Delta y}{b} = \frac{\overset{3\pi/2}{2}\, e^2 \omega}{m v^3} Z = B$$

adiabatic

$$\frac{dE}{dx} * (1 \pm B)$$

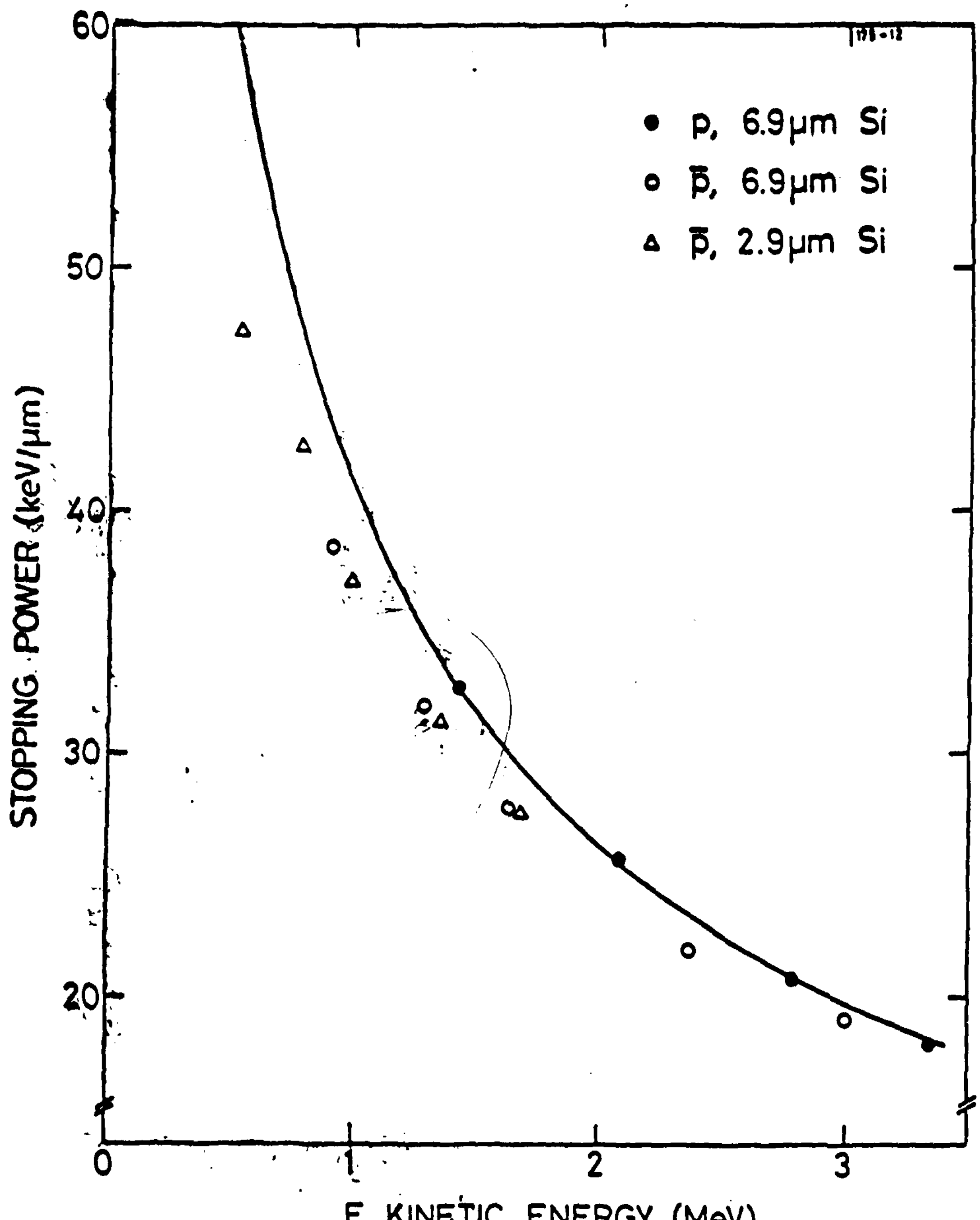
- Z^3 effects important for media with large ω, projectiles with small v^3:

Antiproton trapping
$\bar{p}$ ICF
Plasmas

Ion surface science
Stopping ions
(Z^4 effects)

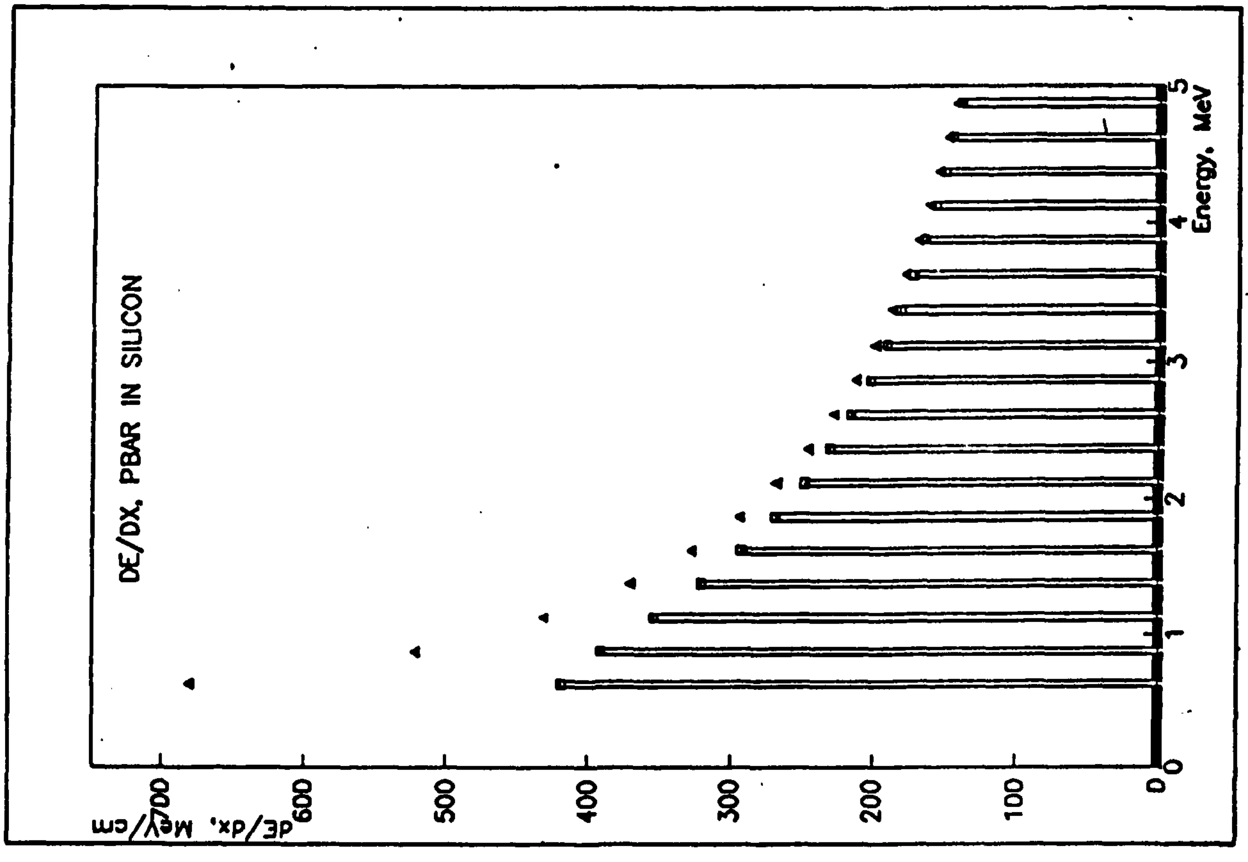
- Agreement with Lindhard may be fortuitous

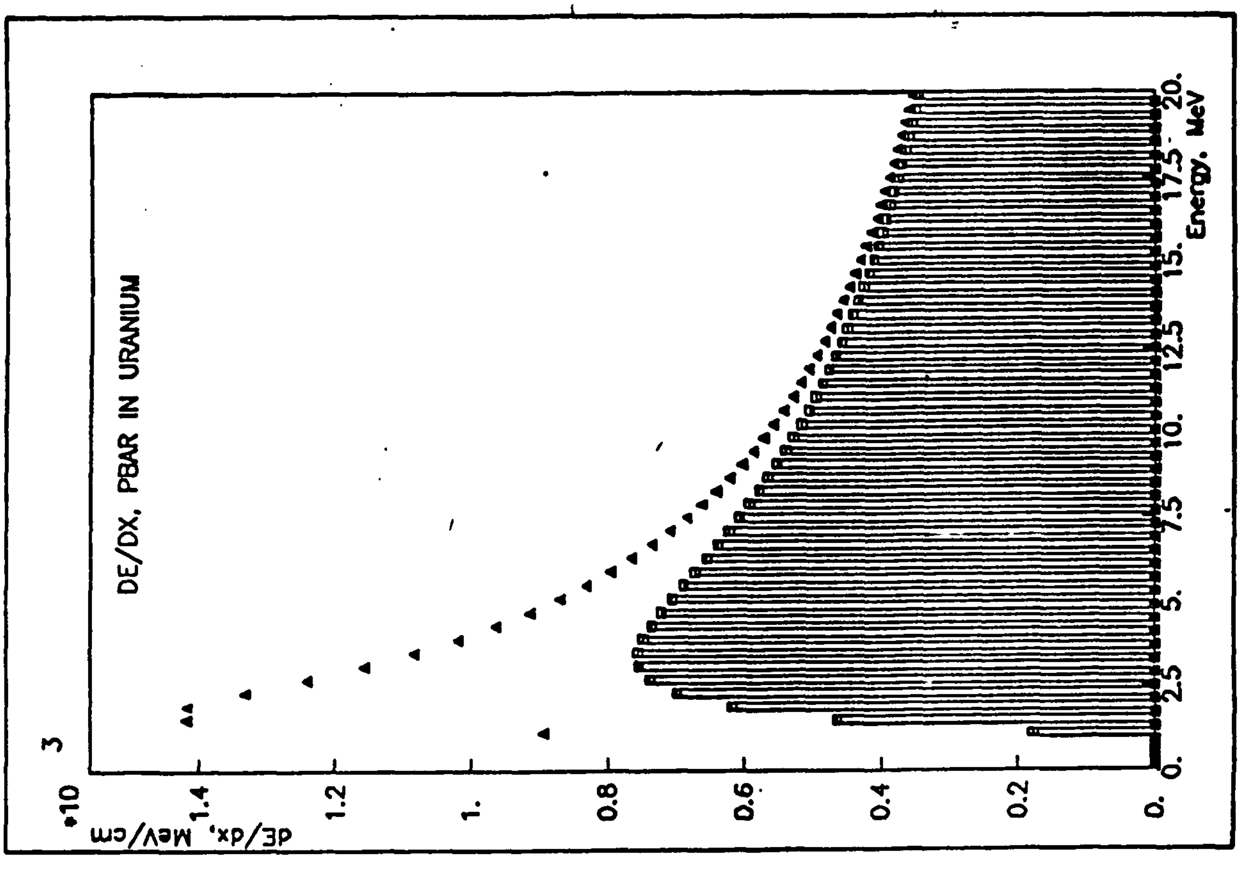
Jackson, McCarthy version
Quantum mechanical Z^3 effects



L.H. Andersen et al.,
CERN EP/89-14
Phys. Rev. Letters

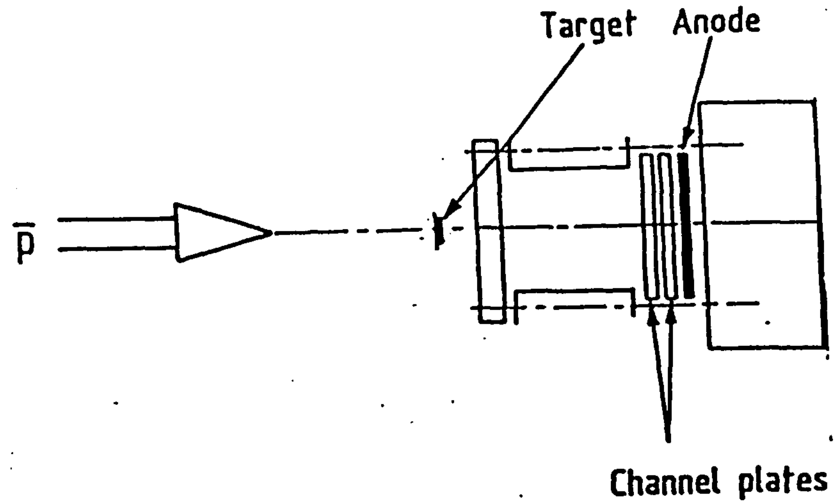
Fig. 2

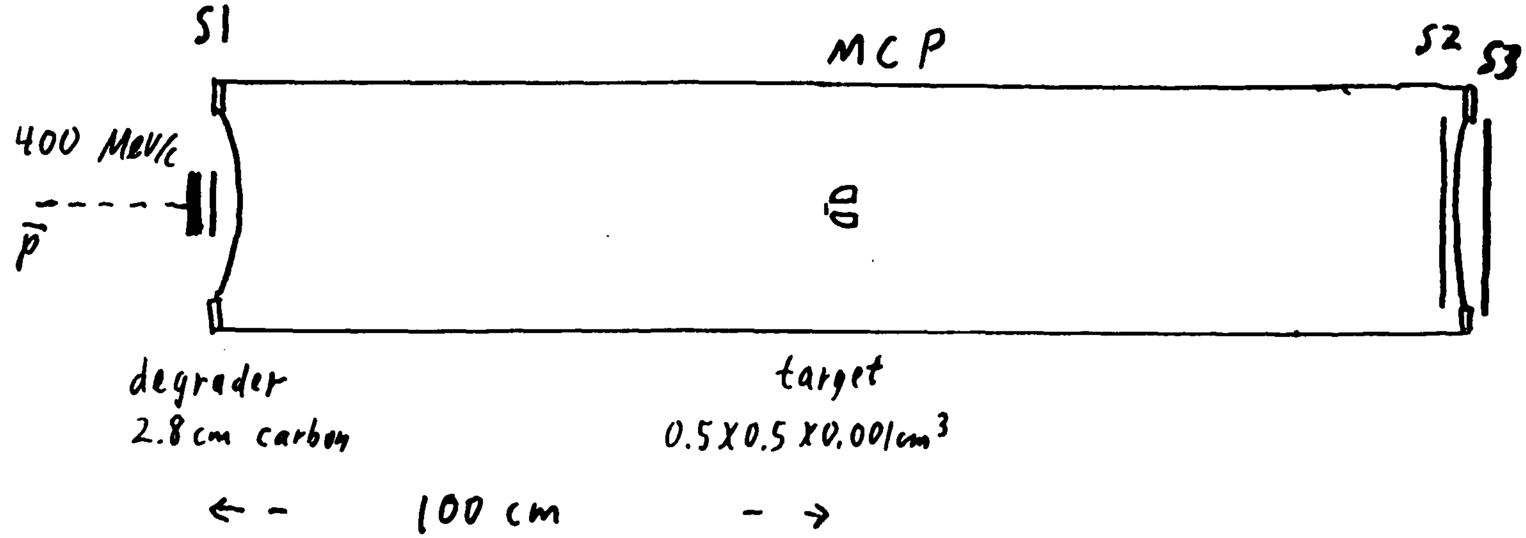

DE/DX, PBAR IN SILICON
dE/dx, MeV/cm
0
100
200
300
400
500
600
700
0
1
2
3
4
5
Energy, MeV

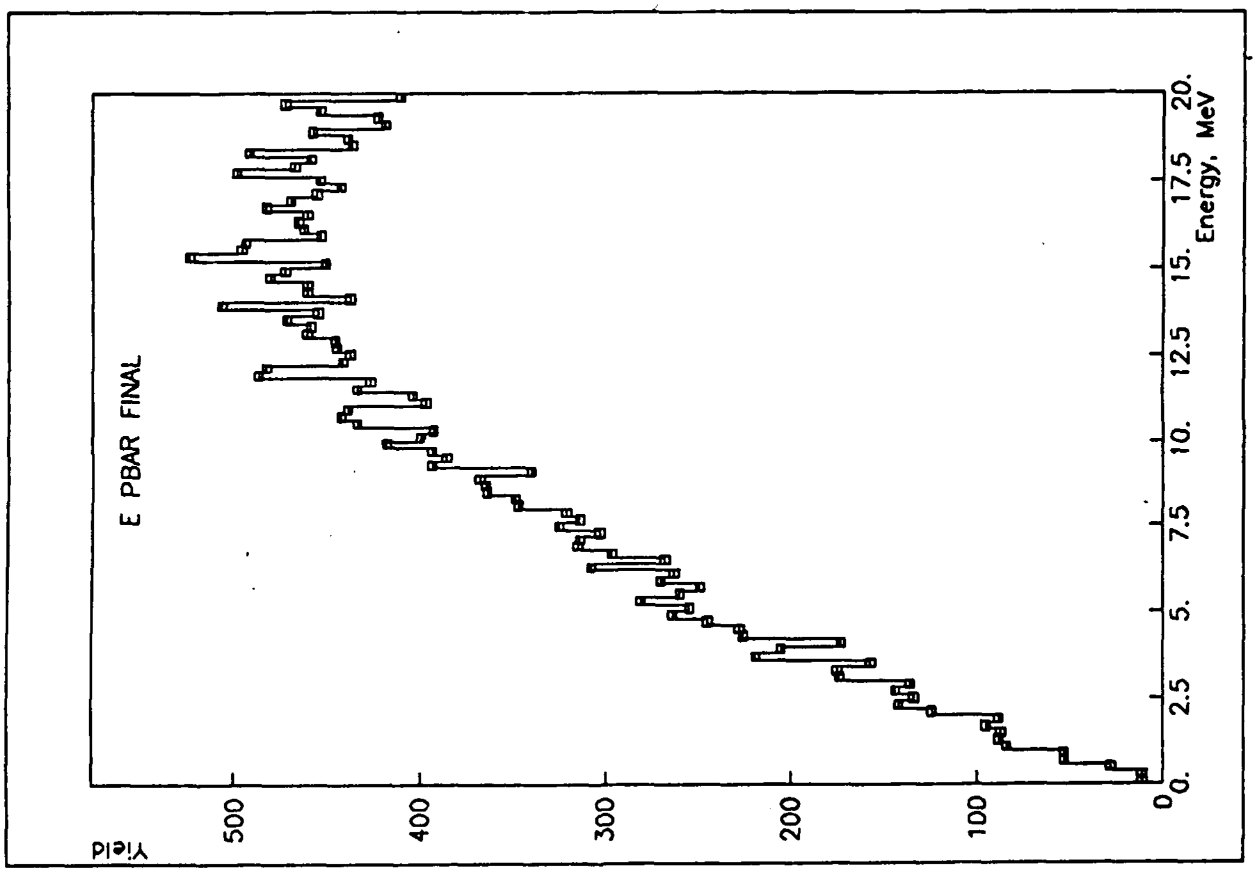

DE/DX, PBAR IN URANIUM
dE/dx, MeV/cm
*10 3
0.
0.2
0.4
0.6
0.8
1.
1.2
1.4
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
Energy, MeV

1 - 8

secondary electrons detection







E PBAR FINAL
Yield
500
400
300
200
100
0
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
Energy, MeV

Yield, Sensitivity Calculations

Event Rate

$\bar{p}$ beam intensity @ 400 MeV/c	500/spill
# spills/hour	1000
degrader effic., $E_{\bar{p}} < 2.5$ MeV	0.29/sterad
Solid angle of target	25 μsterad
MCP efficiency	0.84
annihilations	0.95

Product: 3 events/hour below 2.5 MeV

Energy Loss Resolution at 2 MeV

Nuclear scattering in target	0.003 MeV
Electronic loss fluctuations (13 μ Silicon)	0.015 MeV
Time of flight resolution (0.4 nsec)	0.028 MeV

Quadrature sum 0.032 MeV

Sensitivity

Energy loss difference 13 μ Silicon 0.525 − 0.50 MeV	0.025 MeV
# events 1.4 to 2.2 MeV, 30 hours	55
Uncertainty in difference $0.032 \cdot \sqrt{2}/\sqrt{55}$	= 0.006 MeV

$\frac{4}{3}$ s.d. Barkas effect

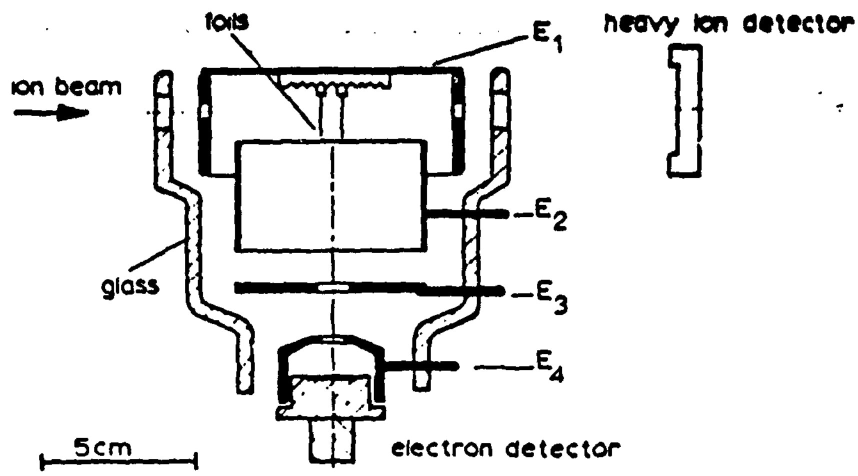


Fig. 1. Apparatus for secondary electron detection.

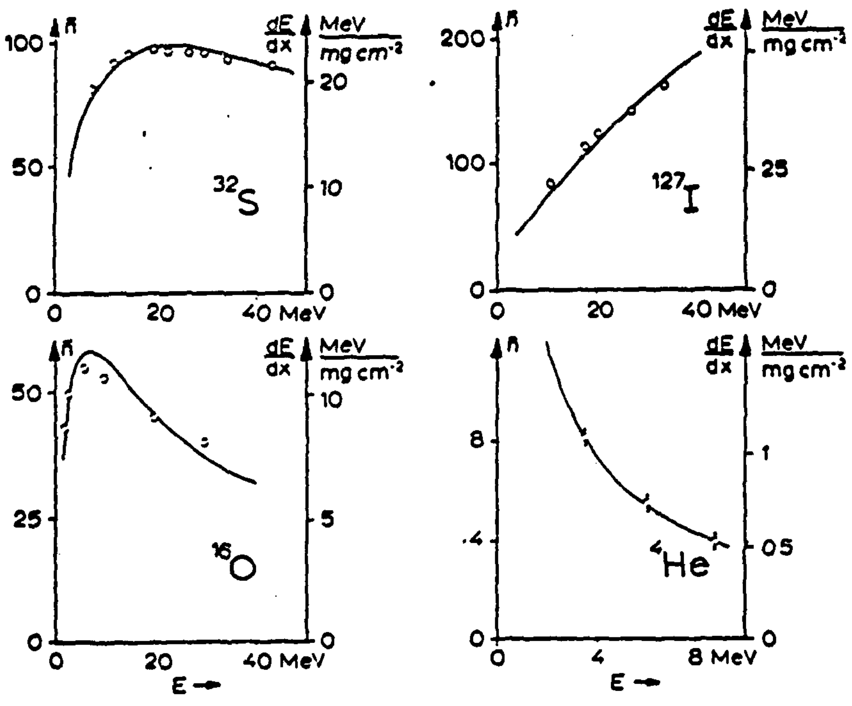
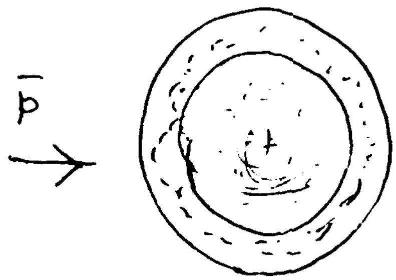
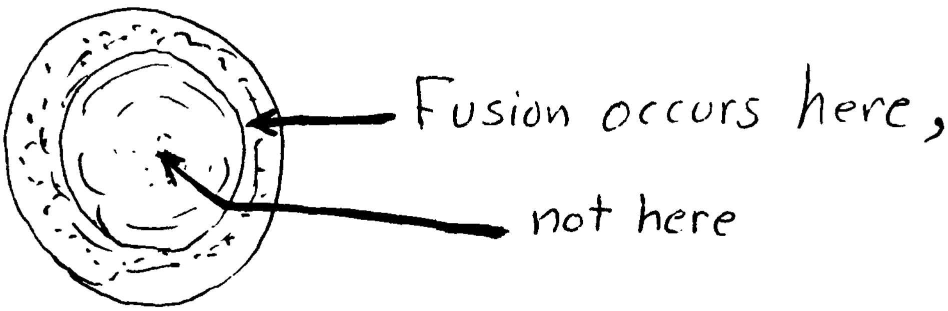


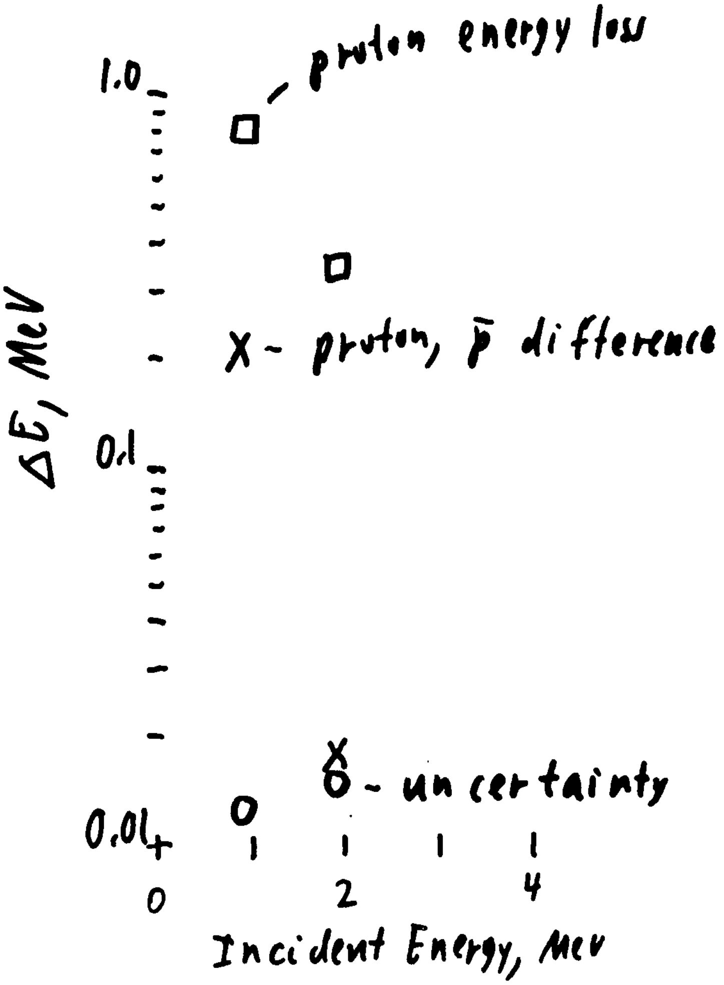
Fig. 7. Average number $\bar{n}$ of secondary electrons (left scales) emitted from one foil as a function of ion energy. Solid lines: Differential energy loss according to Northcliffe and Schilling[12] (right scales). The normalization is different for different ions: $dE/dx = 1$ MeV/mg cm^{-2} corresponds to the following average numbers of secondary electrons: 7.4 (^{4}He), 5.0 (^{16}O), 4.2 (^{32}S), 3.8 (^{127}I).

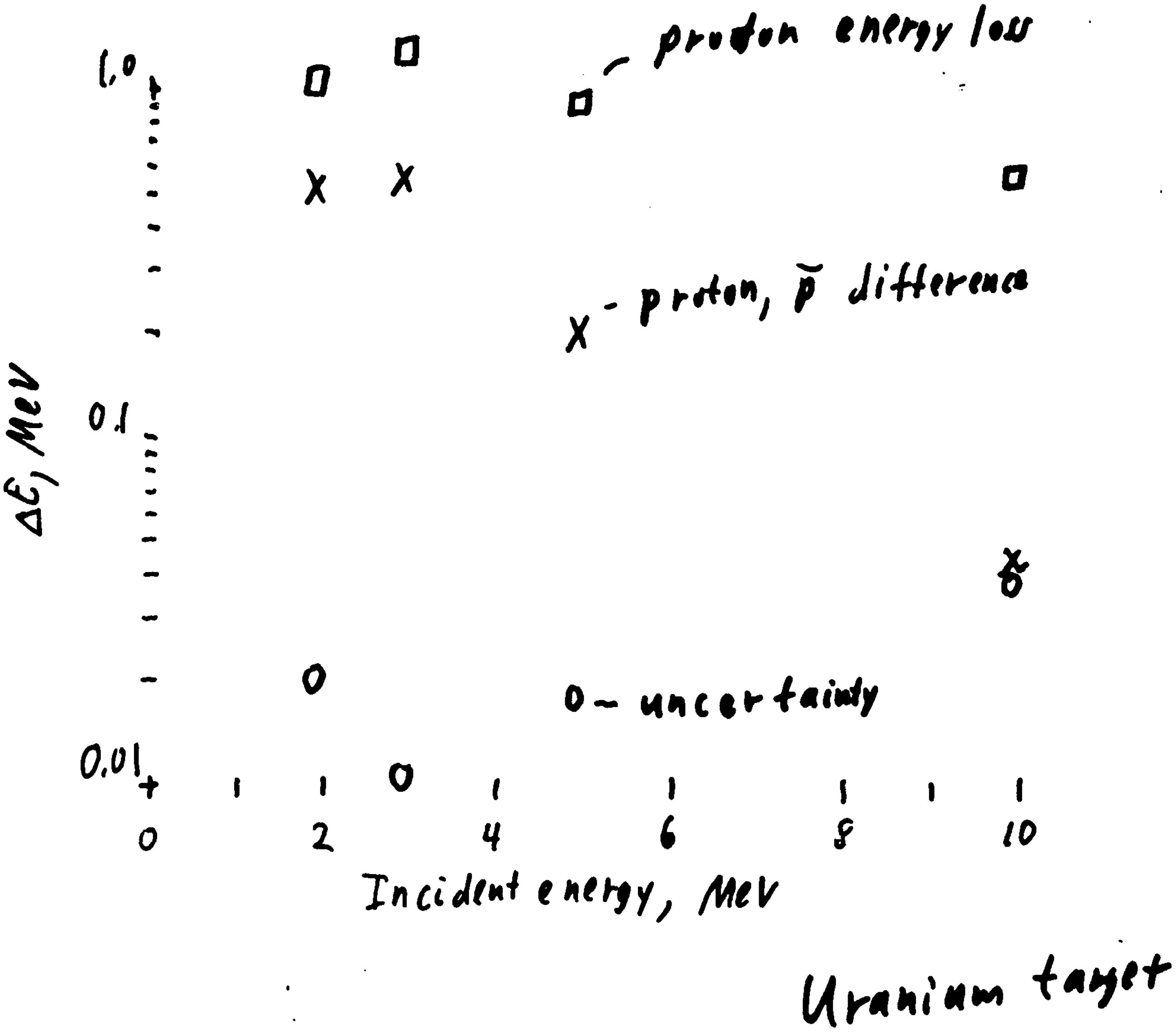
Warm Fusion Shell





Carbun Target





proton energy loss
X - proton, $\tilde{p}$ difference
O - uncertainty
1.0
0.1
0.01
0
2
4
6
8
10
ΔE, MeV
Incident energy, MeV
Uranium target

```
E PROTON VS COS TH

HBOOK    ID =       122                                              DATE  18/04/89                NO = 13

CHANNELS 100 U 0                                                                                          1 O A
          10 N 0         1         2         3         4         5         6         7         8         9         0 V B
           1 D 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 E N
             ***********************************************************************************************************
  ABN        *
  OVE        *
     .999    *      + + ++      3+ +32++ ++ 2 4223222427+2+   23 23+5 24442327+244276+6855365672274652663369683G3456797 *
     .998    *     +    +  +      3 +  + 222+ 2 2+++   22   3543 + 4+2322 ++3 4 24 345344+344346262343+342445565433358 3+33 *
     .997    *          + +++2 3 +  2      ++     +2+2+ 23 + +634 + +2+22 + + + 2  ++2+2+ 7+ 532323+3+2355++2 ++2 2334+225 *
     .996    *                 + + +++ +2+   ++2++ ++    +22+2+ 3 +22+3+2+2+   +2 + 33232+   3+2+   +3+3 +442+2+3+33  +2+32 *
     .995    *        + +   +          +2+   + +    ++  3     ++2    +2 + + +      ++3+   2  +   2+++++++++ 2+ 2+ +2++ 42+++ + *
     .994    *     +    +        + 2+ 3 ++   3     +++     + 2     +    +++ + + 23++2    + 2+   ++++     +22+2++ ++   +2+2 + *
     .993    *            + +        +           +     +              +++  + + +      +     + ++ +  + ++    +   ++3 2++     ++2+ *
     .992    *              +                   +      +     2       ++ + 2    + + 2      +          + + +                2 + *
     .991    *   +     + ++  ++ ++        +       ++ ++   ++++      +             +       ++        +     ++   ++2     2 2 R
     .99     *    ++               +   +      +    +   +        ++ +   ++             +   2    +   +     +        O
     .989    *            +     +        +  +        +    +++     +     + ++             2  2 +        +   ++ ++    E
     .988    *             +     +              +  +                               + +    +         +       ++     G
     .987    *                            +       + + +          +   + +        ++  +                                C
     .986    *           +    +        +   +                      +      +  +                                       4
     .985    *<10       + degrees           + + + + +    +                               +                            5
     .984    *             +                            +                               +             +              3
     .983    *             +        +              +             +     +   +                                    +   2
     .982    *          +                                                                     +                      2
     .981    *                                                           +         +                           +  +
     .98     *                                                                                                       2
     .979    *                                                                                                       2
     .978    *                                                                                                       +
     .977    *                                                         +         +                                   2
     .976    *
     .975    *                                                                          +           +           +
     .974    *           +
     .973    *                                 +                                                    +                3
     .972    *                                                        +
     .971    *                                                                                         +
     .97     *                                                                                                       3
     .969    *
     .968    *                                                                                                       2
     .967    *
     .966    *<- 15 degrees                                                                        +                 +
     .965    *                                                                                                       2
     .964    *
     .963    *                                                                                                       +
     .962    *
     .961    *                                                                                                       3
     .96     *
  UND        *                  2 MeV >  +   +                +                                          +      + D
             ***********************************************************************************************************
 LOW-EDGE    1.          11111111112222222222333333333344444444445555555555666666666677777777778888888888999999999 9
             0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

 *
 * ENTRIES =      4779               PLOT         ----------I----------I----------
 * SATURATION  AT=          31                              I  1092    I   380
 * SCALE  .,+,2,3,.,.,.  A,B,       STATISTICS    ----------I----------I----------
 * STEP =     1      * MINIMUM=0                            I    5     I    13
```

Summary

- 1-5% dE/dx measurements for 1-10 MeV $p, \bar{p}$ at BNL
  Sensitive to 5-50% Barkas effect

- 6 targets @ 30 hours, $\bar{p}$ beam   180 hou[rs]
  10 hours, p beam   60
  240 hours

Carbon, silicon, iron, copper, silver, uranium

Sensitive to w/v^3 dependence

Energy Loss by Particle Beams

Bibliography

Theory of Ionization

1. N. Bohr, Philos. Mag. 25,10 (1913)

2. Bethe, Bloch

3. L.D. Landau & E.M. Lifshitz, Electrodynamics of Continuous Media, Addison-Wesley, Reading, Mass (1960)

4. J.D. Jackson, Classical Electrodynamics, Wiley (1962)

5. R.M. Sternheimer, Phys. Rev. 88, 851 (1952)
Phys. Rev. 91, 256 (1953)
(density effect)

6. L. C. Northcliffe, Ann. Rev. Nucl. Phys. 1963, p.67.
(heavy ions)

7. J. F. Ziegler et al., The Stopping and Range of Ions in Solids, Pergamon (1977)

Hot plasma

8. C.L. Longmire, Elementary Plasma Physics, Interscience (1963)

9. T. A. Melhorn, J. Appl. Phys 52, 6522 (1981)

10. G. S. Fraley et al., The Physics of Fluids 17,474 (1974)

11. E. Nardi et al., Phys. Rev. Letters 49,1251 (1982)

12. S. Karashima et al., Laser & Particle Beams 5, 525 (1987)

13. K. A. Brueckner et al., Phys. Rev. B 25, 4377 (1982)

14. M. N. Saha, Phil. Mag. J. Sci. 40,472 (1920)

Z**3 and Z**4 effects

15. J. Lindhard et al., Mat.-Fys. Meddi. Dansk. Vidensk Selsk. 33, 14,(1963)
16. J. C. Ashley et al., Phys. Rev. B5, 2393 (1972)
17. G. Basbas, Nucl. Inst. & Meth B4, 227 (1984)
18. J. D. Jackson et al., Phys. Rev. B6, 4131 (1972)
19. J. Lindhard, Nucl. Inst. & Meth 132, 1 (1976)

Measurements in Hot Plasma

20. D.H.H. Hoffmann et al., Zeit. fur Physik A Atomic Nuclei 30, 339 (1988).
(333 MeV uranium ions in hydrogen at 2.2 eV)

21. F.C. Young et al., Phys. Rev. Letters 49, 549 (1982)
(1 MeV deuterons in aluminum at 15 eV)

Measurement of Surface Effects

22. H. G. Clerc et al., Nucl. Inst & Meth. 113, 325 (1973)
(electron emission with slow ions)

23. J. H. Cobb et al., Nucl. Inst & Meth. 140, 413 (1977)
(transition radiation)

Measurement of Z**3 and Z**4 Effects

24. M. Budnar, Nucl. Inst. & Meth. B4, 303 (1984)
(0.7 MeV protons in high Z media)

25. L. H. Andersen et al., CERN EP/89-14, January 1989
Phys. Rev. A36, 3612 (1987)
(proton-antiproton differences)

ANTIPROTON INDUCED FUSION REACTION

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UNIVERSITY PARK, PA

PRESENTED AT THE ANTIPROTON TECHNOLOGY WORKSHOP
HELD AT BROOKHAVEN NATIONAL LABORATORY
10 MAY 1989

Antiproton Induced Fusion Reaction

by

R. A. Lewis, G. A. Smith, and W. S. Toothacker

Laboratory for Elementary Particle Science
PENN STATE UNIV

Supported by JPL (NASA)

Antiprotons which stop in Uranium cause fission 100% of the time.

Ref

1) Angelopolus et. al.
Phy Lett, 1988

2) Armstrong et. al.
Zeit für Phys A, 1988

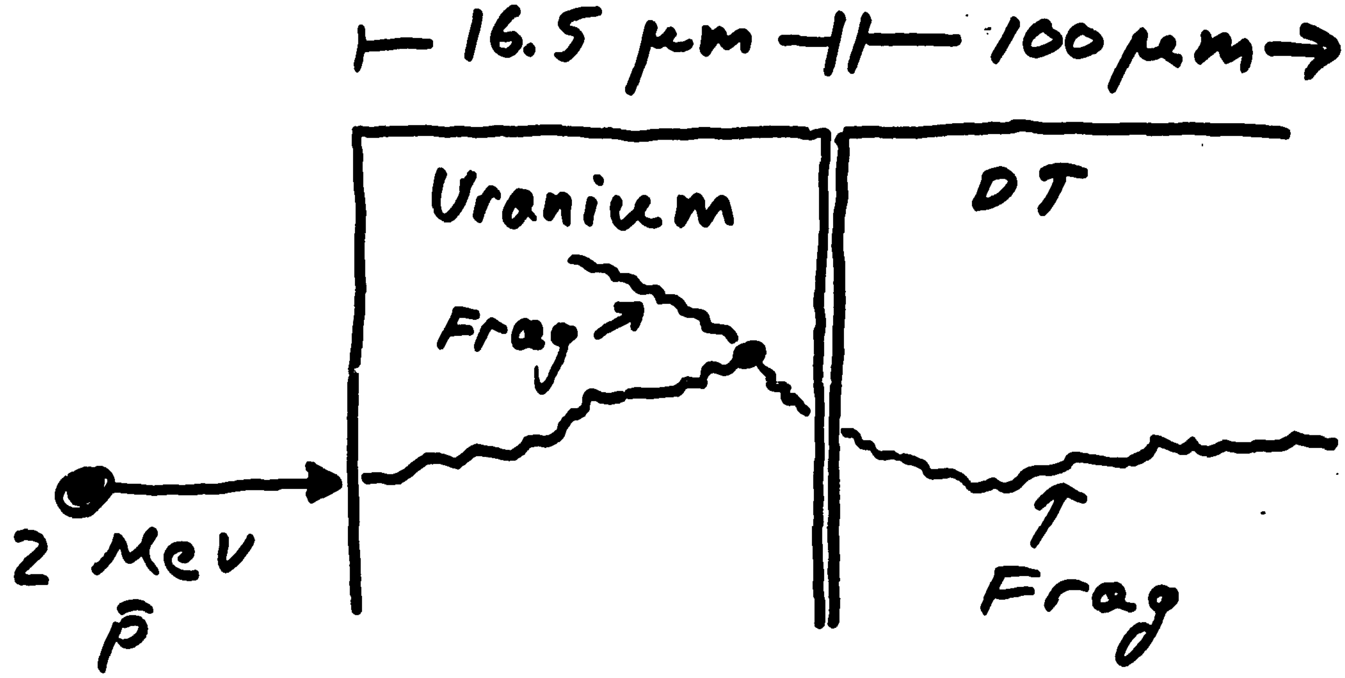
3) Armstrong et. al
Zeit für Phys A,
in press

Applications ?

- Ability to deposit large amounts of energy in a very small volume

- Ability to create very large pressure and temp

- Ability to induce fusion in a DT pellet



Monte Carlo Code

- Track $\bar{p}$ through U until Stop
- Model fission
- Track fission fragment through U
- Track fission fragment through DT
- Track suprathermals through DT
- Calculate & model fusions
- Track alphas through DT

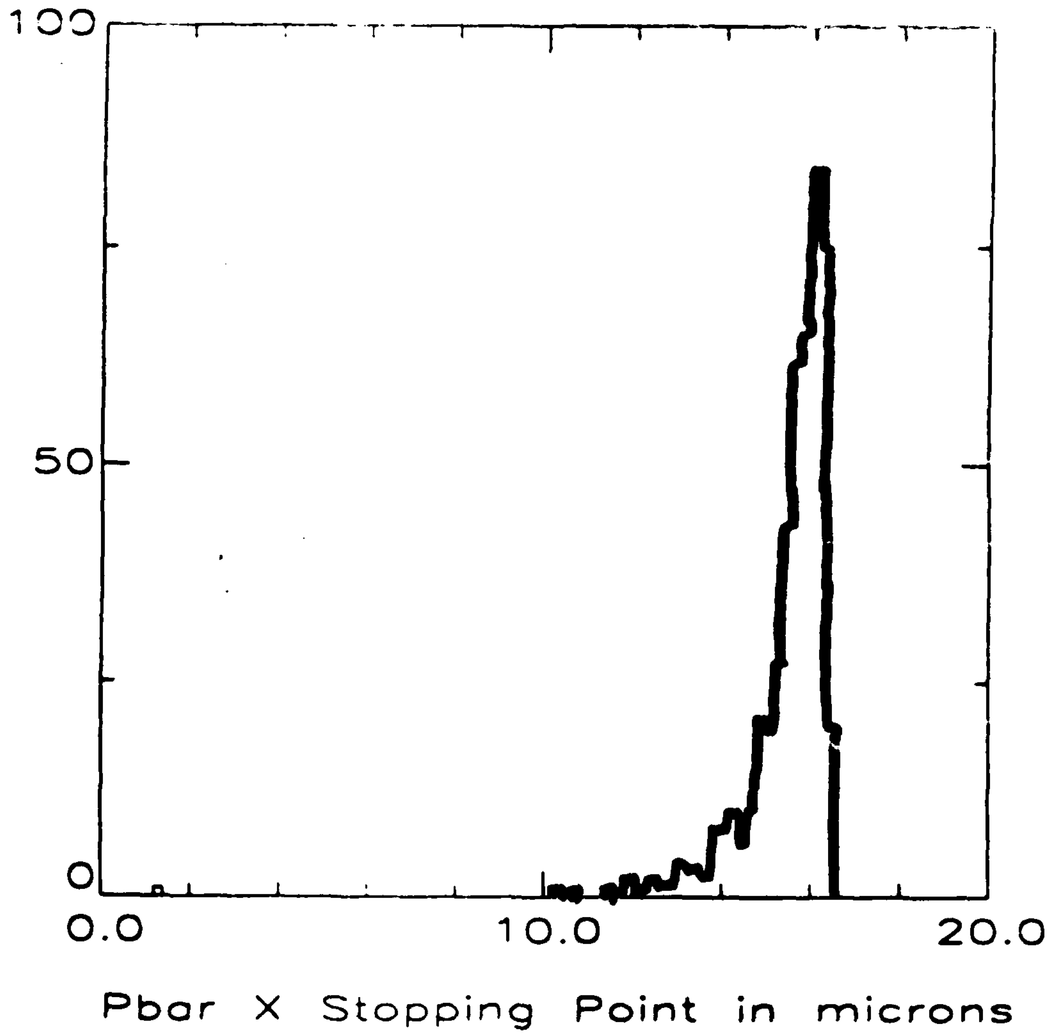


Figure 2

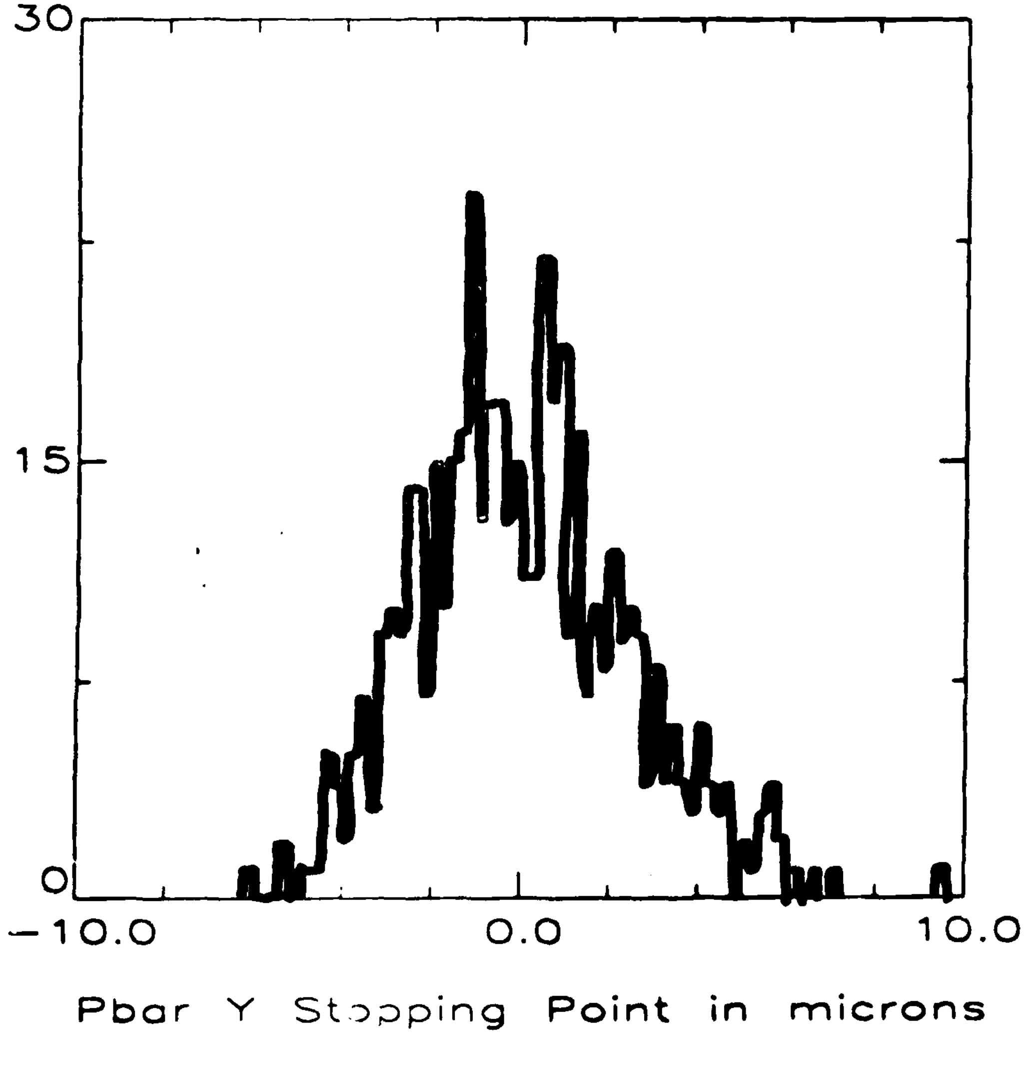


Figure 3

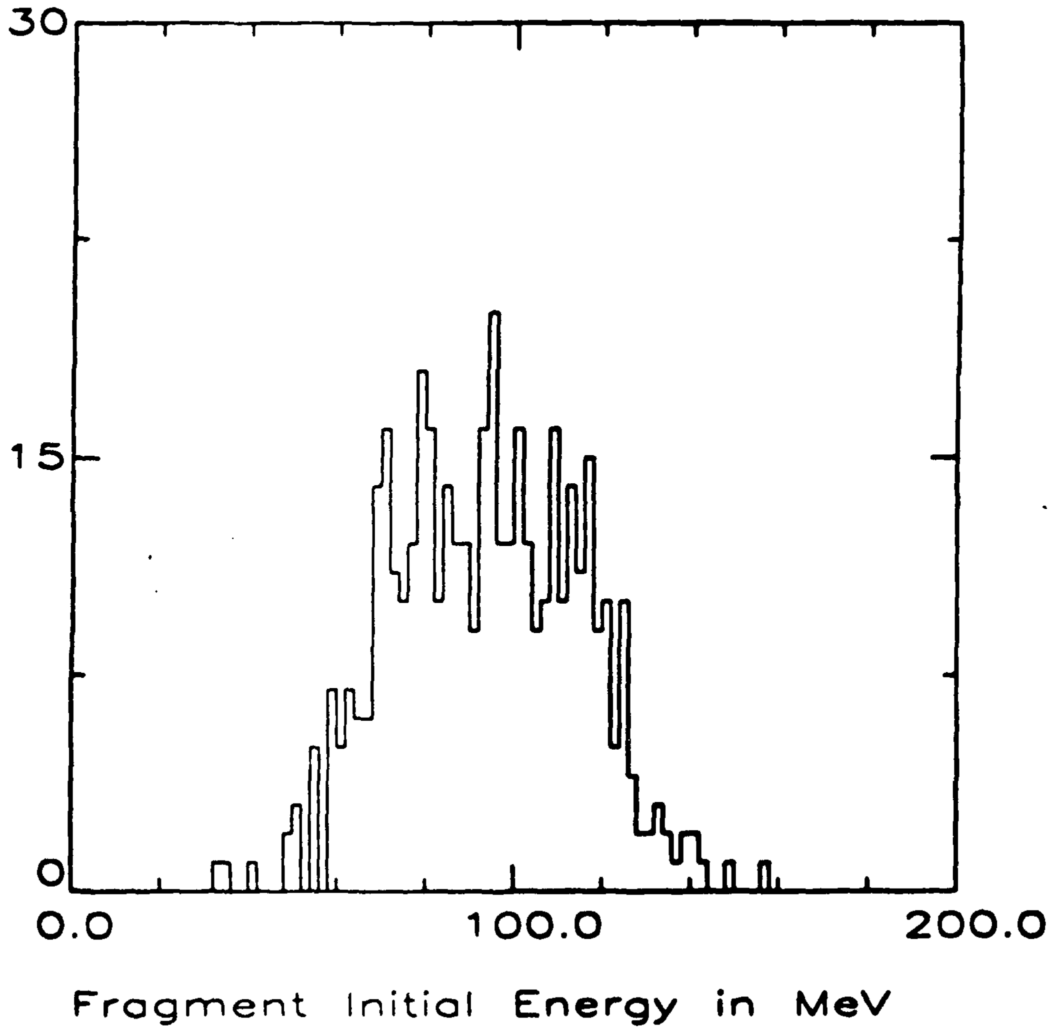


Figure 8

mean = 92 MeV

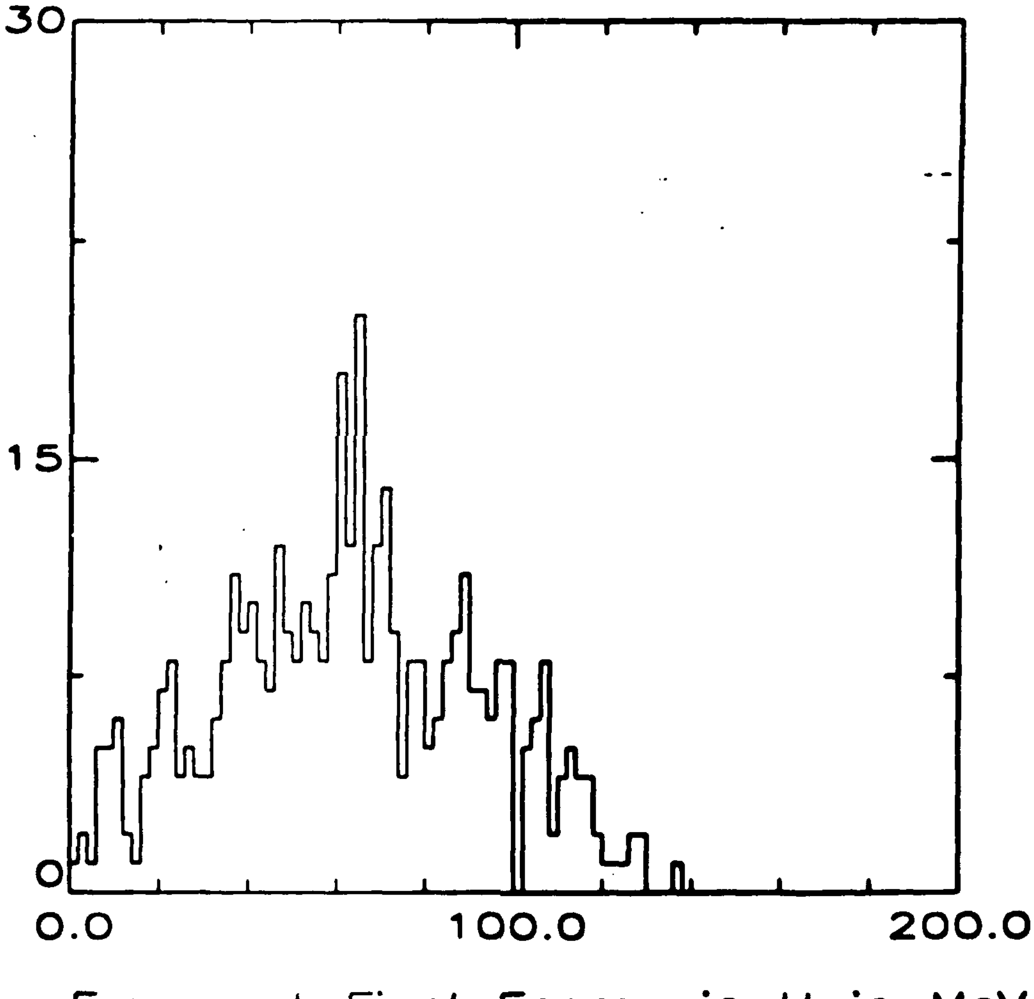
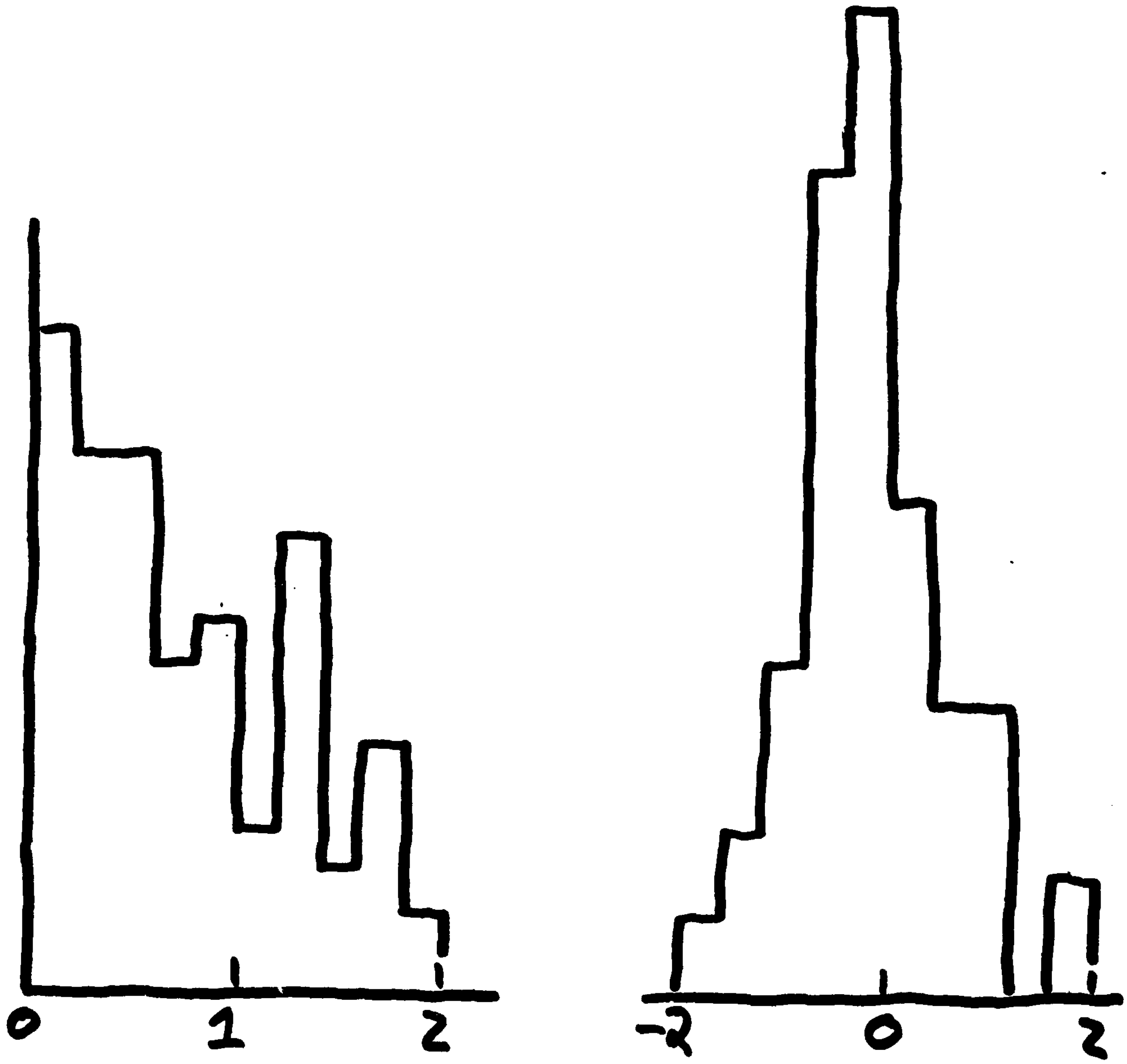


Figure 9

mean = 62 MeV

Fission Fragment Stopping Point in 10 keV DT

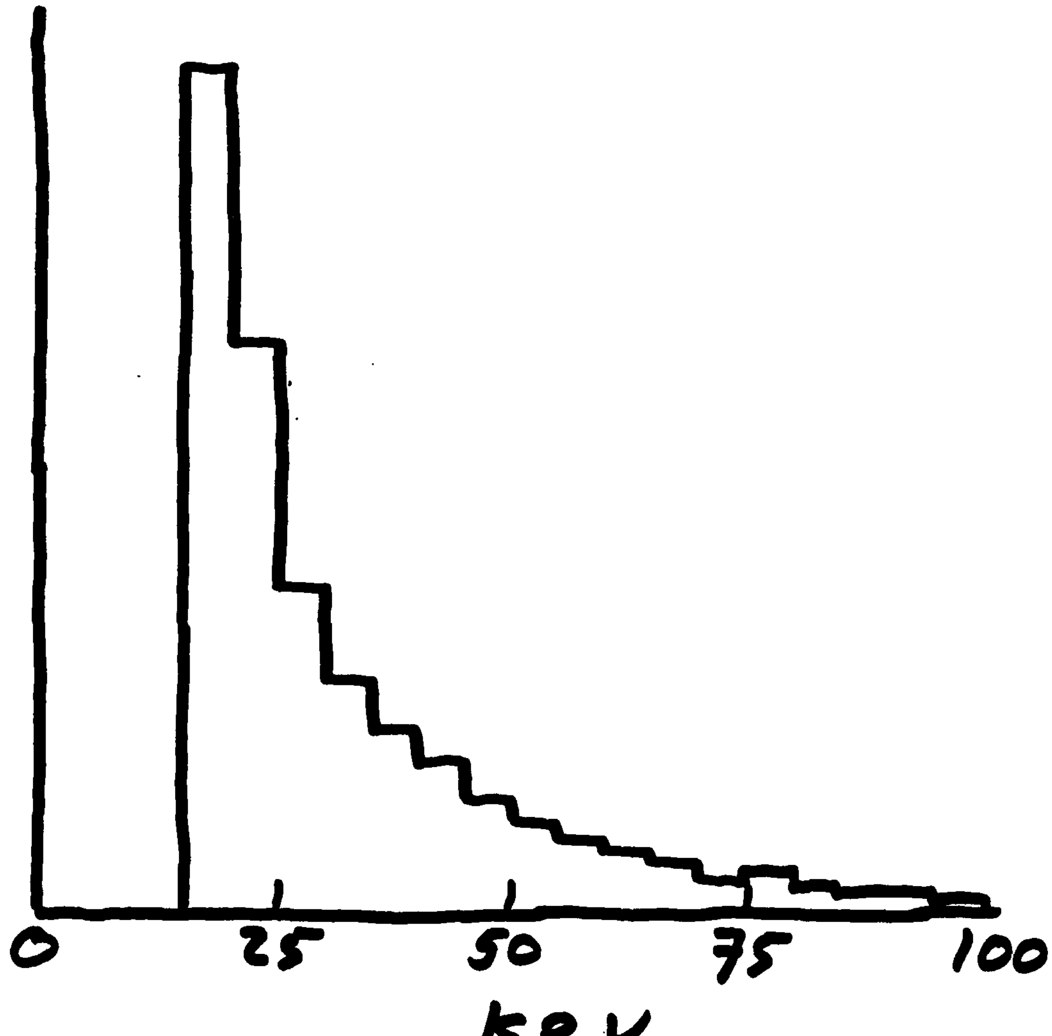


X stopping point in mm

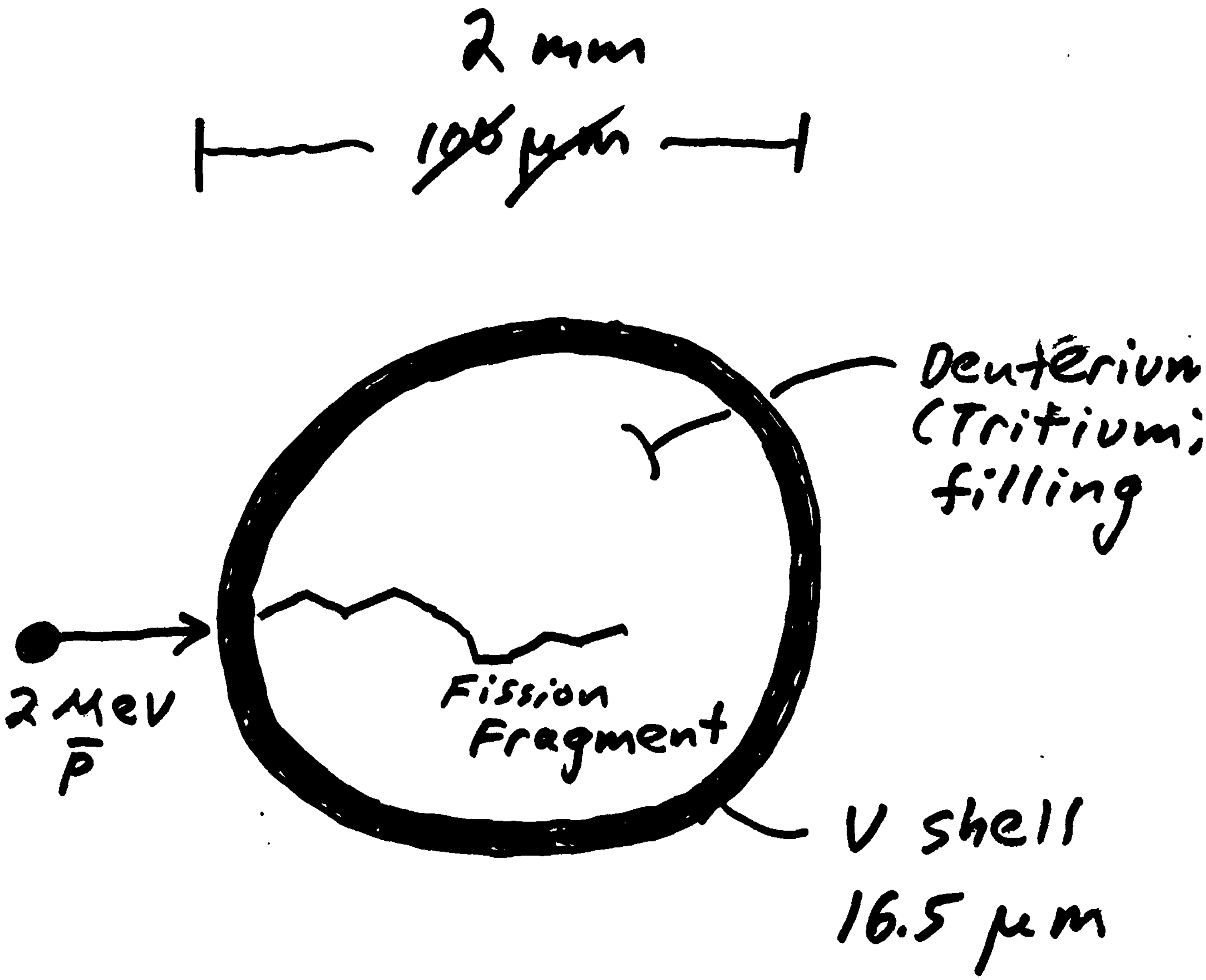
Y stopping point in mm

Energy of Suprathermal Deuterons in 10 keV DT

111 suprathermals per pbar



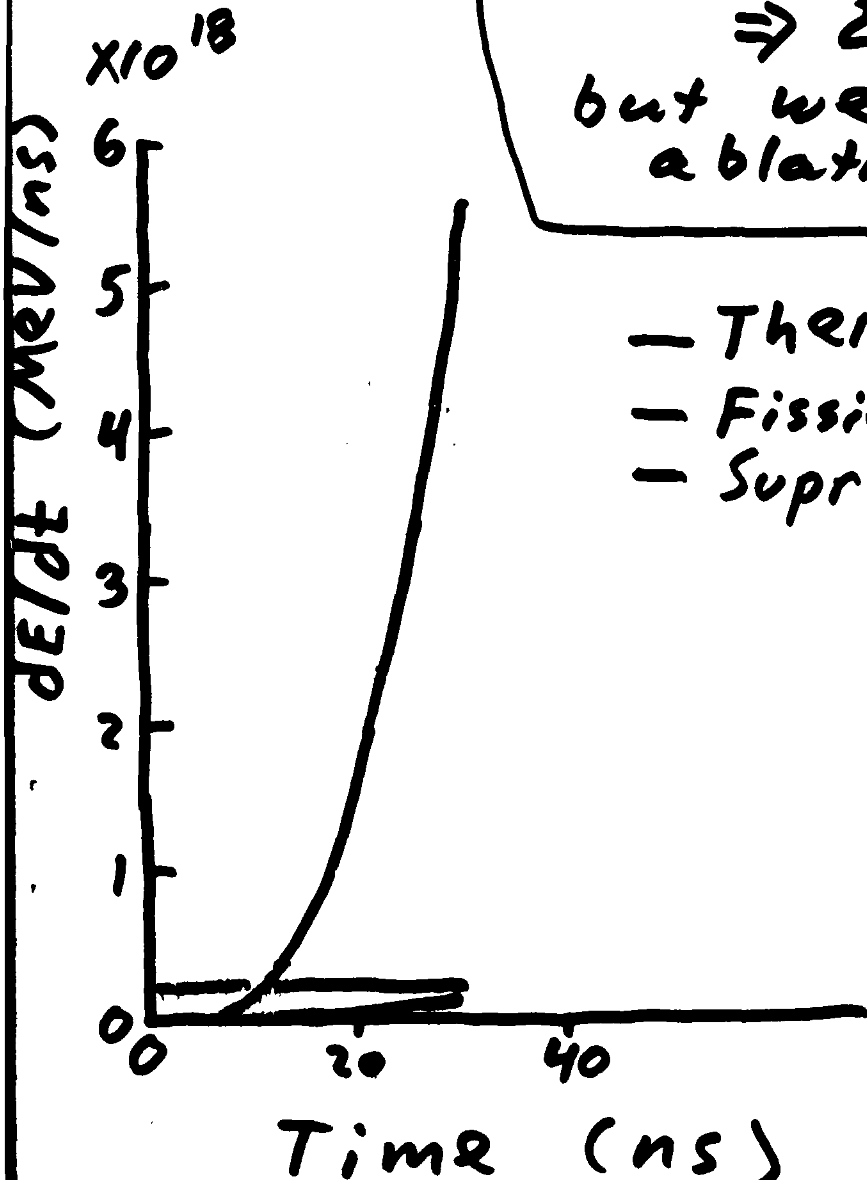
mean = 58 keV


2 mm
~~100 μm~~
Deuterium (Tritium) filling
2 MeV $\bar{p}$
Fission Fragment
U shell 16.5 μm

Assume: 2 mm dia DT pellet
with 16.5 μ U shell
$3.3 \times 10^{15}\ \bar{p}$/ns for 30 ns

Results: 1) Gain $\gtrsim$ 300 (~1100 $\frac{\text{fusions}}{\bar{p}}$)

2) Too slow
Lawsons criteria
$n \tau \sigma v = 1$ (100% burn)
$\Rightarrow \tau = 360$ ns
but we estimate
ablation time $\gtrsim$ 10 ns



Need more help from Suprathermals.

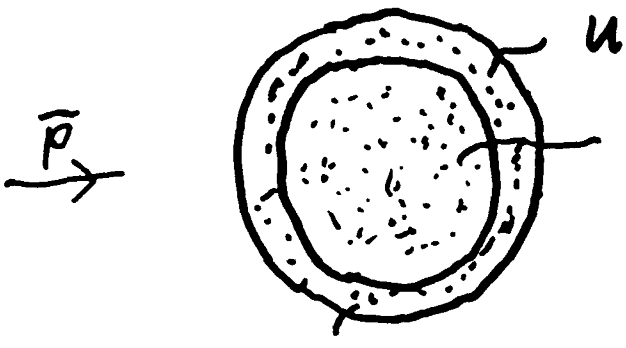
(1) Try adding a moderator like Li or look at reactions involving heavier atoms

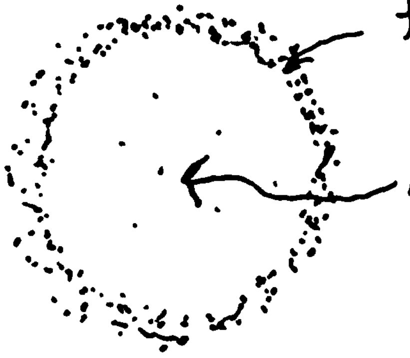
- better energy transfer
- increased stopping

Preliminary look at Li filled pellet:

- frags stop in < 0.25 mm (< 2 mm in DT)
- Suprathermal Li have mean energy $\gtrsim$ 90 keV (58 keV in DT)

Warm Fusion Shell





$n \tau \sigma v$

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